CEMENT AND LIME MANUFACTURE

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New Cement and Concrete Testing Laboratory in Sweden.

IN our number for November, 1945, a brief notice was made of the new laboratory in Stockholm of the Swedish Cement and Concrete Research Institute. By the courtesy of the Institute we are now able to give a fuller description of this up-to-date laboratory, which was opened last year. The work of the Institute is divided into three departments, namely, chemical, physical and technical. The equipment is not confined to the standard equipment found in most other laboratories, the installation being specially designed for the work in view.

Fig. 1.—The New Cement and Concrete Laboratory at Stockholm.

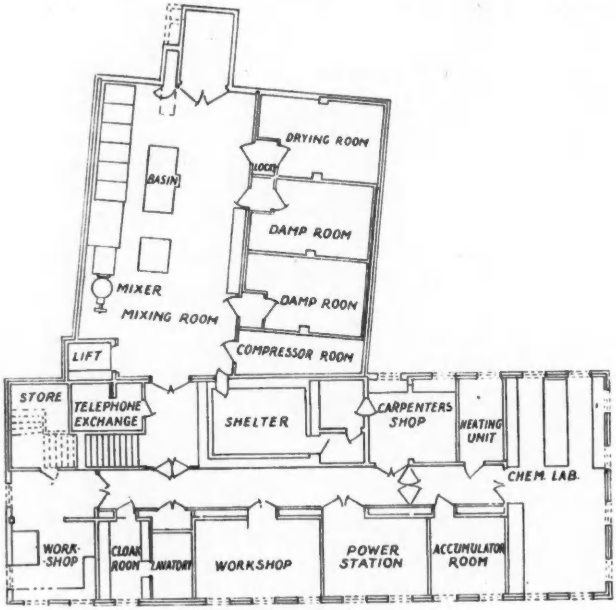

Fig. 2.—Plan of Basement.

Fig. 3.—Ground Floor Plan.

Plan of the Building.

The building (*Fig.* 1) has been specially built for the purpose in view, particular emphasis being placed on physical investigation. The building has three floors and a basement. The plan allows for future extensions by the erection of a further wing to give an H-shape plan with the concrete mixing, casting, and testing departments in the middle. Plans of the two wings now in use are given in *Figs.* 2, 3, 4, and a section in *Fig.* 5. In order to prevent vibration from the machinery in the basement reaching the upper floors, the machines have been erected on a rubber-insulated foundation. The building is designed to permit the addition of a further two floors. The casting department is separated from the administrative department by a party wall to prevent the vibration of the machinery being

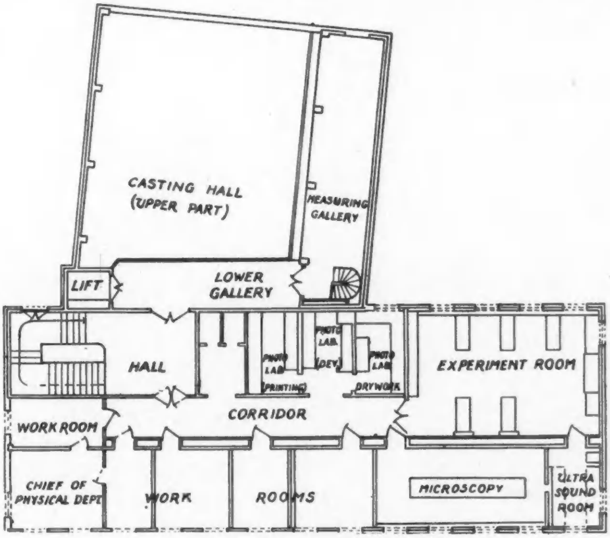

Fig. 4.—First Floor Plan.

transmitted to the laboratories and other rooms. The mixing room, store and compressor room are in the basement; the casting hall passes through to the top of the building. Along one wall of the casting department are two balconies at the levels of the upper floors, used for measuring instruments.

Construction.

The buildings are of reinforced concrete frame construction. The outer walls are 6 in. thick, insulated externally with 5 in. of Siporex taken about 4 ft. below the ground, where it is cemented and asphalted. The inner concrete walls are from 5½ in. to 6 in. thick. The corridor and staircase walls are load-carrying, all the other walls being partitions; this provides for future alterations in the plan. The flooring is oak parquet in the corridors and workrooms; in the experiment and other rooms, a concrete topping about 2 in. thick covered with

glued-on matting is used. The frame of the mixing and casting departments is separated from the administrative building by a wall in which 16 mm. of glass wool matting is inserted in order to improve sound insulation. The floor of the casting room is 21 in. thick, and in it are cast mounting devices for jacks for use in load tests. The roof is of concrete $4\frac{3}{4}$ in. thick, with 6-in. of insulating material.

In connection with studies on the plastic properties of concrete it was decided to use the building to investigate plastic deformation of the structure. For this purpose a number of pressure gauges were inserted in certain of the members. The pressure gauges are in two sizes, 30 mm. and 65 mm. in length respectively; *Fig.* 6 shows the smaller type with the connecting coupling. The warping of the measuring cylinders under external stresses are recorded inductively by the aid of two opposite fields from a double primary coil and a secondary coil, which are displaced relatively to the resultant field. The primary circuit is measured from a note generator with constant oscillation frequency and current strength, but the

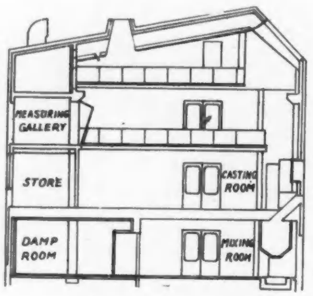

Fig. 5.—Section through Casting Department.

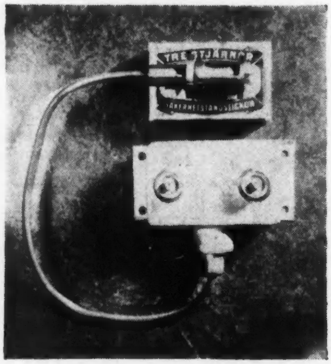

Fig. 6.—Inductive Pressure Gauge for Deformation Tests.

voltage induced in the secondary circuit is amplified and compared with a normal voltage calibrated against the load of the cell or the displacement of the coils. On being measured, the normal voltage passes through the same amplifier as the induced voltage, whereby variations in the characteristics of the amplifiers are eliminated. The measuring cells have the same modulus of deformation axially as stone of equal size and of normal strength.

In the casting department, where uniform humidity and temperature are required, heating is by air conditioning. In order to counteract the effects of cold air and heat radiation at windows and doors, heaters are placed between the outer and inner windows and between the outer and inner doors. These heaters are automatically controlled so that the spaces between the windows and doors are kept at the same temperature as the air in the room. In order to

prevent changes of temperature due to the cooling effect of the large end-wall, this is heated by means of hot-water pipes embedded in the wall. As the laboratories require an even temperature with freedom from dust, heating is by hot-water pipes built into the beams at floor level. In the basement heating pipes are laid above the floor insulation.

Ventilation of the administrative and laboratory building relies chiefly on the intake of fresh air through the corridors. For each group of adjacent fume cupboards there are separate extractors on the roof. In the casting department it is important that the temperature and relative humidity should be kept constant and the air circulation as uniform as possible. Experiments with models were therefore carried out. The air in the casting department is intended to be maintained at 20 deg. C. and 60 per cent. relative humidity. The air is treated by two conditioning apparatus in an attic. After the air has passed through the conditioning apparatus and has been filtered, it is forced into a space

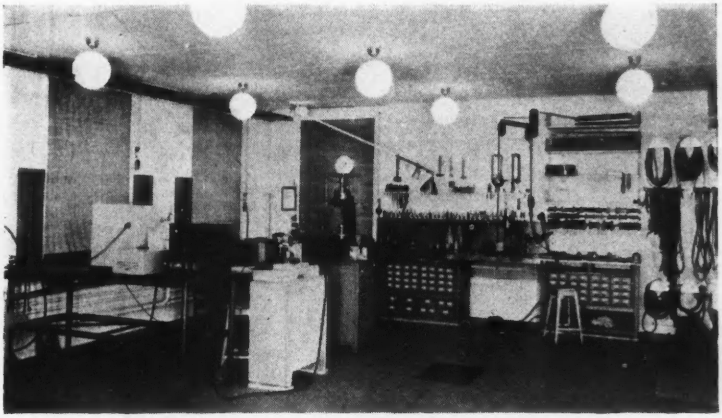

Fig. 7.—One of the Physical Laboratories.

under the roof provided with slits along the entire length of the room. In order to secure the greatest possible uniformity in the air distribution, air is forced into this space through four pressure conduits and adjustment dampers. From the roof the air moves slowly down towards the casting department, and is extracted through gratings in the floor placed in two rows along both long sides of the room. The air in the casting department is kept at a pressure slightly above atmospheric, so that air from outside cannot enter. All windows are electrically heated between the panes and the end wall is fitted with built-in heating pipes, so that transmission losses are small. The air drawn into the building only requires to have a temperature 4 deg. C. higher than that of the room with an external temperature of — 20 deg. C.

Electricity is generally alternating current, but direct current is also used for certain laboratory purposes.

Chemical Laboratories.

There are two chemical laboratories and one weighing room on the ground floor, and another in the basement. In the basement there is a 15-k.v.a. furnace for work at a high temperature. A maximum temperature of 2000 deg. C. can be reached. There is also a plate mill, an hydraulic press for test cubes, a fume cupboard for chemical work, and a special fume cupboard for three 13-gall. carboys. Here are kept the stock solutions and raw materials. The basement laboratory is fitted with a work-table fastened to the wall, with drawers and porcelain basins, and two movable tables.

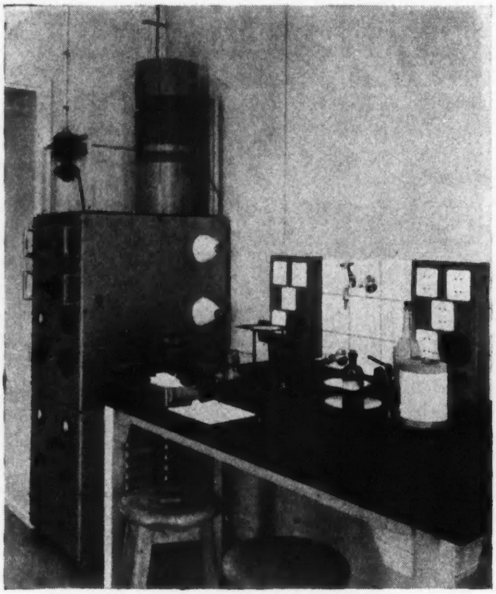

Fig. 8.—Ultra-Sound Transmitter.

One of the two laboratories on the ground floor is arranged for analytical work. On two sides work-tables are fixed to the walls. On another side is a titrating table. On the remaining wall are two fume cupboards, constructed with an upper air-tight top and a lower glass top which can be lowered. Between the glass top and the back is a slit about ⅜ in. wide for extraction. The upper exhaust aperture is between the two tops, and under the aperture is a ledge about 4 in. wide, the object of which is to prevent particles from falling from the exhaust pipe and spoiling the experiment in the cupboard.

The other laboratory on the ground floor is chiefly intended for synthetic work. In the main it has the same equipment as the analytical laboratory, but there are no titrating tables. Instead, it has a bench along one of the long walls, with lead covering and two sinks with taps for warm and cold water, and water-distilling apparatus. On one wall are cupboards for chemicals and apparatus.

The weighing room is fitted with a wall shelf covering the whole of one wall and a weighing table against another wall. The table top is made of concrete with a limestone slab on top. It rests on eight thick rubber pads, placed on brackets fastened to the wall and is not in contact with the wall. Owing to the weight of the slab and its supports, it is completely free from vibration, even when there are strong vibrations in the walls. All laboratory tables are stained black with aniline black ; other woodwork is varnished.

The Physical Laboratories.

The four physical laboratories on the upper floor have in the main similar equipment irrespective of their size and the use to which they are to be put. Thus

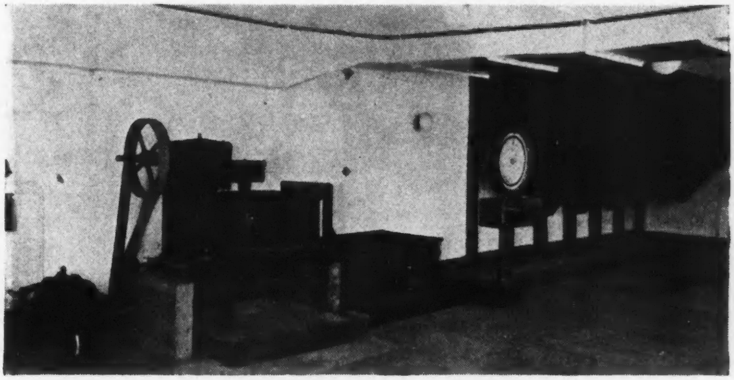

Fig. 9.—Concrete Mixer, Weighing Apparatus and Materials Bins.

all the rooms are fitted with steel wall shelves at table height for connecting to movable work-tables of standard design. The walls and ceiling have built-in plugs for fixings. Three of the laboratories are electrically screened against the metallisation of the walls, floor, and ceiling. The windows can be covered with wire-netting screens. In two of the rooms are floor sinks. All the rooms are provided with acid-proof basins and mixers for hot and cold water, taps with hose-pipe connections, and compressed-air for drying glassware. It was thought desirable to group a number of different investigations around common apparatus, such as frequency generators, amplifiers, oscillographs, etc., so that a minimum of time is required for coupling and moving instruments, while the apparatus can better be used for different purposes. By this arrangement there is more intimate

collaboration in various measuring problems, and the experience of different research workers more readily becomes common knowledge. In view of these considerations, a large room (*Fig.* 7) accommodates several investigations simultaneously, with five or six working places and a common work-table. Connecting with this room is a smaller room for work with high-frequency oscillations, in which is installed an ultra-sound transmitter for research into setting times, elasticity investigations, etc. The third room is intended for optical research, but its equipment enables it to be put to general uses. For etching work, etc., in connection with microscopy, there is a fume-closet of the same type as in the chemical

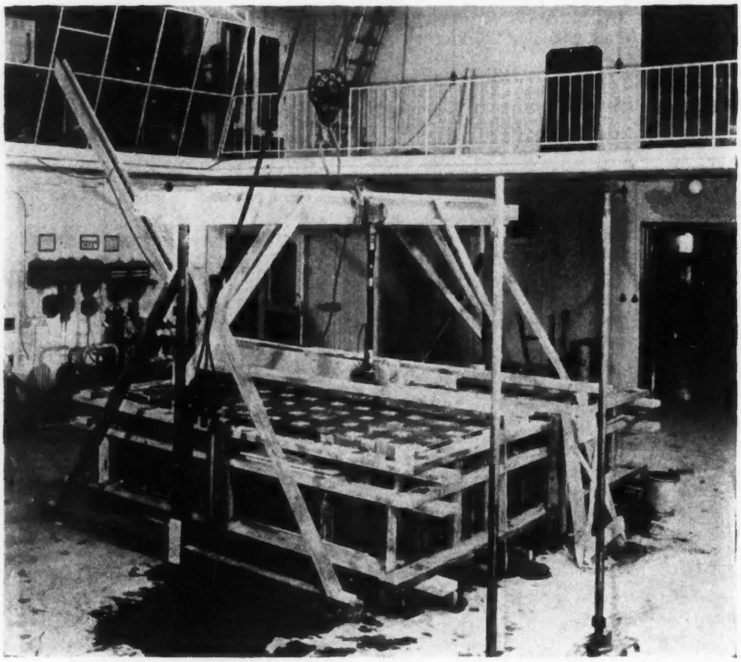

Fig. 10.—Test for Static Pressure and Wave Amplitude of Vibrated Concrete.

laboratories. The fourth room is used as an office with facilities for its use as a laboratory. The equipment of the physical laboratories also comprises electric apparatus for measuring warping and stresses, and electrical and mechanical oscillators of various type within a frequency band between 0 and about 30 megacycles (*Fig.* 8). For the photographic recording of time experiments, there are cathode ray oscillographs of various types, with amplifiers, cameras, etc. For recording low-frequencies there are two electro-magnetic oscillographs with built-in cameras. A universal microscope, a smaller microscope, micro-

scopic cameras, apparatus for tension-optical research, spectrographic apparatus, and X-ray apparatus will be added later.

Mixing and Casting Department.

In the basement are the concrete mixing-room and three store-rooms for samples. Above these rooms is the casting department and, connected therewith, the carpenter's shop. The mixing-room occupies an area of 1,260 sq. ft. The mixer (*Fig.* 9) is a counter-current machine with a capacity of $3\frac{1}{3}$ cu. ft. Aggregates are stored in bags and heaps, and also in six bunkers with bottom discharge. Under the bunkers is a truck with weighing apparatus running in a depression in the floor. The contents of the truck are tipped into the mixer by a pneumatic hoist. The casting-room is 50 ft. long by 36 ft. wide by 28 ft. high, and it is also intended to be used for carrying out tests for which purpose beam testing machines of 12 tons and 100 tons capacities are installed. In order to be able conveniently

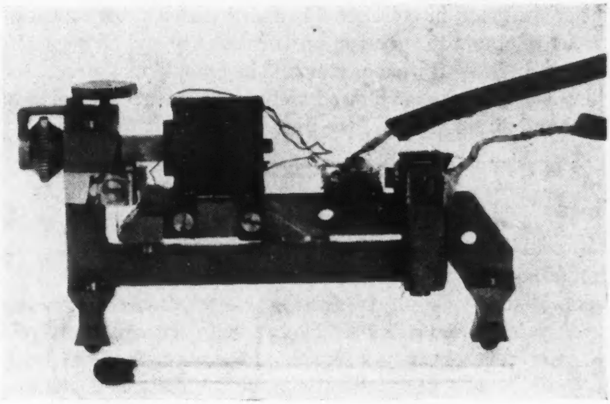

Fig. 11.—Apparatus for Measuring the Deformation of the Surface of Test Pieces.

to follow experiments in progress and to make measurements without having to move the instruments, a gallery has been built at first-floor level.

The Cold Laboratory.

The cold laboratory, on the ground floor, consists of two rooms, each with a door towards the casting department and insulated from each other by a lining of expanded cork, 12 in. thick. The refrigeration machinery is in the basement, and consists of a two-stage ammonia compressor, driven by a 15-h.p. three-phase motor. Its capacity is 1,750 B.T.U. per square foot per hour at -45 deg. C. gasifying temperature and $+ 15$ deg. C. for incoming cooling water. The effective consumption is 8·5 kw. The lowest temperature that can be obtained is —20 deg. C.

Fig. 11 shows an automatically-recording extensometer designed for application to the surface of the object to be measured. It is at present being used for deformation investigations on concrete test specimens. The following advantages

are claimed for this type of apparatus. The gauge is of robust design and can be applied to the specimen without risk of damage when the specimen fractures. The accuracy of the instrument corresponds to a specific extension of 0·01 per cent. By means of the electrical method of measurement used the course of deformation can be recorded with a needle and chart, a sling-oscillograph, or a cathode-ray oscillograph. It is possible to place the specimen in any desired atmosphere and take a remote reading without disturbing the specimen. Static and dynamic processes can be recorded without changing the apparatus. By superimposing vibration on the specimen it is possible to apply loads of such brief duration that the bulk of the plastic deformations are eliminated, and only those associated with the hysteresis effect remain. The extensometer is used in a study of the plastic deformation of concrete which is in equilibrium with a surrounding fluid medium, which in the first instance consists of water with or without the addition of electrolytes. Several kinds of alcohol will also be used. The test specimens are made in steel moulds and vibrated; they are also vacuum-treated in order to obtain the greatest possible density and homogeneity.

Fig. 11 shows an investigation on concrete in a mould measuring 10 ft. by 10 ft. by 2 ft. 8 in. The concrete is vibrated and measurements are being made of the static pressure and displacement of the fresh concrete.

A New Flask Shaker.

THE "Microid" shaking machine, which carries up to four 500-ml. flasks each half-full of liquid, is marketed by Messrs. Griffin & Tatlock, Ltd., of Kemble Street, London, W.C.2. The machine is silent in operation, the power consumption is 60 watts, and it is continuously variable in speed from zero up to 500 oscillations per minute. In a round-bottom flask the liquid can be made to swirl around on a hollow horizontal axis. In a conical flask the liquid can be made to rise spirally up the walls; in returning in droplets to the bottom it is brought into intimate contact with the gaseous phase and is aerated for such purposes as hydrogenation. In the operations of dissolving and dispersing solids, extracting residues, and so on, the machine saves time and accelerates the processes.

The Plasticity of Cement Paste.

AN interesting discussion in the structure and behaviour of a cement paste, with and without the addition of air-entraining substances, is contributed by Mr. T. C. Powers (Manager of Basic Research of the American Portland Cement Association) to the Journal of the American Concrete Institute for November, 1945.

The author states that the dispersed state of Portland cement in water is defined as that state in which interparticle attraction in a fresh paste is absent or so weak that it has no appreciable effect on the physical properties of the fresh paste. Experiments and reasoning from general principles indicate that dispersion would be undesirable because it would increase the rate and amount of sedimentation and promote particle-size segregation in cement paste ; it would destroy the plasticity of the pastes and give them the properties of a fluid, a probably undesirable change ; it would have no beneficial effect on the rate of hydration during the early stages through an increase in exposed surface area because the whole surface is normally exposed to water even when the particles are flocculated. A reduction in interparticle attraction short of actual dispersion should reduce the water required for a given slump, but it would not improve workability except in unusually rich mixes. It would increase " bleeding."

Air entrainment requires an increase in paste content and a reduction of water content to maintain a given slump. It reduces strength but improves frost resistance. It improves workability and reduces bleeding. Air entrainment, together with some reduction in interparticle attraction, affects paste content and water requirement in the same way as air entrainment alone, but the increase in paste content is smaller and the reduction in water content is greater than when there is no reduction in interparticle attraction. Air entrainment offsets the undesirable effects of reducing interparticle attraction on plasticity and reduces bleeding.

Some materials sold as dispersing agents may have merit because of effects not related to dispersion. The assumptions have been made that a normal cement paste is composed of separate flocs (clusters) of cement grains such as may be seen when a small amount of cement is suspended in a large volume of water ; that water for hydration does not penetrate the flocs and hence that the cement cannot hydrate as well as it might do ; and that the water that is " trapped " in the flocs does not contribute to workability. It is then further assumed that the flocs of cement grains can be dispersed by adding an agent which causes the grains to acquire electrostatic charges and thus to become mutually repellent ; and that when the cement grains are thus dispersed they hydrate more rapidly and to a greater extent than when flocculated. Moreover, it is assumed that when the particles are brought to a state of mutual repellency the amount of bleeding or " settlement-shrinkage " is reduced. Dispersion is said also to improve resistance to frost action. Most of these assumptions seem plausible, but they are not compatible with the results of recent research and on the whole are believed to be untenable on either a theoretical or empirical basis.

When the force of adhesion between a powder and a liquid is less than the surface tension of the liquid, the powder and the liquid are difficult to mix unless a suitable wetting agent is used. If the adhesion tension exceeds the surface tension only slightly, a wetting agent will be noticeably helpful. On the other hand, if the solid and liquid show a strong mutual attraction, the liquid will spread over the solid surface without outside aid. Observation shows that the wetting of Portland cement by water could hardly be improved by a wetting agent, unless the cement has acquired a " water-repellent " coating. The degree of solubility of the constituents of cement and the rapid formation of hydrates that occurs immediately on contact with water show that Portland cement has a strong affinity for water. The attraction is so strong that each cement grain becomes completely surrounded by water even though in a dilute suspension the grains are clustered. So far as the writer knows, no one has seriously contended that cement needs a wetting agent.

When a powder is readily wetted, so that each grain becomes surrounded with water, the grains are necessarily separated by at least a thin film of water. Because of this, the wetting of a powder by immersion in a liquid is sometimes referred to as dispersion. However, it is advantageous to draw a distinction between wetting and dispersion. The term wetting pertains to the spontaneous spreading of a liquid over any shape of surface, not to particles alone. Dispersion, on the other hand, pertains only to particles. It is the opposite of flocculation, agglomeration, or coagulation. Wetted particles may be in either a flocculated or a dispersed state. Flocculated particles in a liquid may be held together by forces acting across separating films of liquid ; hence, a flocculated state is not necessarily one requiring particle-to-particle contact.

According to present-day theories, the interparticle force in an aggregation of particles in a fluid medium is made up principally of (1) An ever-present force of attraction (van der Waal's forces) which causes adjacent particles to adhere ; and (2) An electrostatic force of repulsion that opposes the force of attraction ; this repulsion is strongly dependent on the environment of the particles and is therefore subject to control. The control of interparticle force may involve controlling the kind and concentration of electrolytes, or the use of certain kinds of organic molecules or colloids.

Because of the nature of the relationships between distance of separation and intensity of repulsion and intensity of attraction, two particles may have minimum potential energy when they are separated by a small but definite distance. Hence, even in the flocculated state, suspended particles may tend to remain slightly separated.

Dispersion.

Dispersion has been described as a spontaneous process whereby particles bearing like electrostatic charges " spring apart and stay apart " by distances easily observed with the microscope. However the forces of repulsion in a suspension are effective over only very short distances. Indeed, if the particles were separated only by the effective distance of repulsion they would appear to

be in contact under ordinary magnification. Nevertheless, if the particles are very small, they may be capable of dispersing themselves far beyond the range of interparticle forces by their Brownian motion, a vibration caused by unbalanced impacts of the molecules of the surrounding medium. If a particle is small enough, the forces of the impacts received simultaneously from different directions do not balance and the particle thus acquires motion.

Particles having Brownian motion wander at random and tend to bounce away from each other when they collide. If the forces tending to keep the particles in motion exceed the force of attraction between the particles, then a state of dispersion will spontaneously be maintained. On the other hand, if the forces of attraction between the particles exceed the forces tending to keep the particles in motion, then a state of flocculation, or agglomeration, will persist. Interparticle repulsion is not necessary for dispersion, but the more the interparticle attraction is cancelled by interparticle repulsion, the smaller the amount of kinetic energy required to keep the particles dispersed. Brownian motion can occur to a significant degree only among colloidal particles. Hence, Portland cement cannot be caused to disperse spontaneously, for cement particles are predominantly microscopic, not colloidal.

Even when spontaneous dispersion is not possible, dispersion can be effected mechanically. Stirring a suspension tends to separate the particles, particularly if the stirring is violent. The degree to which the particles will become separated on stirring depends largely on the intensity of the interparticle attraction. Of course, mutually repellent particles should be more easily dispersed than those which have some tendency to stick together.

The foregoing discussion shows that some of the phenomena described in connection with the use of dispersing agents with Portland cement actually can occur only among particles that are of truly colloidal dimensions. Whether or not spontaneous dispersion takes place is of little practical consequence. The important question is whether it is necessary or desirable to cancel or reduce the forces of interparticle attraction that normally predominate over the forces of repulsion in a suspension of cement particles in water.

The greater the interparticle attraction, the stiffer will a paste seem to be when it is stirred. In comparatively concentrated suspensions such as cement pastes, where interparticle attraction predominates over repulsion, the suspension behaves more like a solid than a fluid. The other effect appears when suspensions are allowed to settle. If the forces of attraction predominate, the large and small particles settle together. If the forces of repulsion predominate or if the net force of attraction is very weak, particles that would remain in contact when quiescent become separated as they fall through the liquid during sedimentation. The cause of this may be seen by considering two particles of different size adhering to each other at the beginning of their fall through the liquid. The drag of the liquid on the small particle will be greater per unit mass than that on the large one; therefore a force tending to separate them will develop. If this force, which depends upon the difference in the size of the particles, exceeds the force

of attraction, the particles will separate, the larger particles falling more rapidly. When the attractive forces are very weak, and especially when the particles are mutually repellent, the sediment that is formed tends to be non-uniform in composition, the proportion of coarse particles increasing towards the bottom of the sediment. Moreover, the sediment formed is compact and difficult to redisperse, whereas a flocculated sediment is bulky, soft, and easily restored to its original state in the suspension. This feature of the behaviour of the dispersed suspension is very significant with respect to the question of dispersing cement.

A criterion for dispersion applicable to colloidal suspensions is not altogether applicable to temporary suspensions of non-colloidal particles ; dispersion cannot mean exactly the same thing for both types of suspension. Yet circumstances seem to require using the same term for both cases ; indeed, there is considerable justification for it. The dilemma is avoided by thinking in terms of interparticle attraction instead of the repulsion that is implied by the word " dispersion." The following definition of dispersion is used in the discussion of cement paste that follows : When interparticle attraction in a fresh cement paste is so weak that it has no appreciable effect on the behaviour and physical properties of the paste, the particles in the paste may be said to be dispersed. By this definition we would call any suspension dispersed in which the interparticle attraction is zero or negative. This would not disagree with other definitions applied to colloidal suspensions. But we would also call a suspension dispersed if the interparticle force was positive, but too weak to have an appreciable effect on the physical properties of the suspension. The definition does not rest on the presence or absence of particle clusters ; neither does it imply that dispersion is a spontaneous process. This definition admits the possibility of various degrees of interparticle attraction among the particles in flocculated suspension, that is, suspensions in which the attraction has an effect on flow properties, etc. Consequently we can discuss two questions, one pertaining to the desirability of producing dispersion, and one pertaining to the desirability of changing the intensity of interparticle attraction in a flocculated paste.

Dispersion of Portland Cement.

There is no question but that cement particles in a normal paste are flocculated. The process may be visualised as follows. Under the action of a mechanical mixer, cement particles probably tend to be dispersed during the first few seconds of contact with the water. Chemical reactions begin immediately and continue at a relatively high rate for a period of not over five minutes—probably less than two minutes—during which time the electrolyte concentration in the mixing water increases rapidly. The electrolytes (apparently the hydroxyl ions) bring about flocculation of the cement particles. During the same period a coating of hydrates forms on the cement grains. Once this coating has formed, and the electrolyte solution has reached full strength, the rate of reaction becomes very low and thus the cement remains comparatively dormant chemically. This state lasts for a considerable period, usually about an hour. The paste remains plastic during this period, and, if left undisturbed, undergoes sedimentation.

The sedimentation of cement pastes has been shown to be essentially like that of other concentrated suspensions of flocculated mineral powders. Various experiments have been carried out that reveal the effect of flocculation on this process. Steinour observed the sedimentation of emery particles both flocculated and not flocculated, and found that flocculation reduced the amount of settlement at all concentrations. The amount of settlement is influenced by the concentration of the flocculating agent. Results of experiments with Portland cement show that the addition of alcohol up to about 50 per cent. by volume increased the sedimentation volume ; higher concentrations of alcohol reduced the volume, finally to a point below that for water alone. All suspensions were flocculated to the extent that no separation of particle sizes could be observed, except the one in straight alcohol. In the latter, most of the cement settled out quickly, the largest particles concentrating toward the bottom of the sediment while the very finest flour remained in suspension, even after 24 hours, probably because of Brownian motion. It is reasoned that in settling from dilute suspensions the particle-flocs, in making contact with the sediment, tend to form arches enclosing relatively large spaces which contribute to the bulkiness of the sediment. The greater the extent to which such arches are able to withstand the pull of gravity, the greater will be the final volume of the sediment. It seems reasonable to assume that the greater the interparticle attraction the greater the strength of the arches and the bulk of the sediment. Therefore, the factors that control interparticle attraction should control sedimentation volume. It appears that the forces of interparticle attraction in cement-water paste are not as high as they might be and that if a change in the force of flocculation is desired it could be either an increase or a decrease, according to choice. Tests with various dispersing agents for Portland cement show that they produce a condition similar to that found with cement alone in pure alcohol, but only in very dilute suspensions. Used in concretes or cement pastes in proportions recommended for field use, they do not cause such dispersion ; the pastes clearly show the effects of interparticle attraction. There is evidence, however, that these agents weaken the forces of attraction.

The effect of flocculation on the rate of sedimentation is subject to the following general rule : in dilute suspensions, flocculation increases the rate of sedimentation over the average for the dispersed material ; in concentrated suspensions flocculation decreases the rate. Portland cement pastes as used in practice may be classed as concentrated suspensions ; accordingly they settle more slowly than they would if the particles were dispersed. At high dilution flocculation increases the rate of sedimentation because the displaced water is able to flow mostly around the flocs, each floc acting much like a single large particle. But at some sufficiently high particle-concentration the particles form a floc-structure so continuous that the displaced water can flow only through the floc-structure itself. In an intermediate range the flow is partly around and partly through the flocs, a condition giving rise to what may be called "channelled bleeding."

The actual conditions in a normal cement paste seem to be about as follows. Before or during the process of flocculation the cement particles become coated

with hydrates and the coating acquires a layer of adsorbed water and ions. The particles are so concentrated that when flocculation occurs they do not draw together into discrete groups, but form a continuous network. The bonds of the network are, it would be imagined, at points on adjacent particles that would be in contact were it not for the strongly attached adsorbed layer. It has been shown that the particles cannot exist as separate flocs, and that the particles are normally surrounded with water. The evidence is so strong as to be little short of proof that a cement paste may be considered as one large floc; hence all the water in the paste is within the floc.

So far as the effects of " bleeding " are concerned the results obtained when the particles are subject to the force of flocculation are clearly preferable to what they are when the particles are free from that force. During the " bleeding " of concrete the aggregate soon forms a static framework within the cells of which the paste continues to settle. Even with a normally-flocculated paste the settlement is enough to weaken the bond with the under-surfaces of the aggregate particles. Dispersion would not only increase this effect but also would tend to destroy the uniformity of the hardened paste by promoting stratification. If cement pastes were not normally flocculated it would seem advisable to add a flocculating agent. It is plain that any claim that dispersion is a means of reducing bleeding, or shrinkage before hardening, is based on knowledge of the effect of dispersion on the settlement of dilute suspensions and not of the effect on pastes. Also, any deductions based on the assumption that the cement particles in a normal paste exist in discrete flocs from within which water for hydration is excluded are bound to lead to erroneous conclusions, for the evidence is overwhelming that no such condition exists.

Flocculation is essential to the plasticity of granular suspensions. When the particles are not flocculated, the mixture behaves like a fluid; it flows under any force, however small, and it can have only the cohesiveness of the liquid itself. When the particles are flocculated, but the dilution is such that individual flocs exist, the mixture probably partakes both of fluidity and plasticity—plasticity increasing with increase in particle concentration. In normal cement pastes the particles are so concentrated that the behaviour of the paste is almost wholly that of a solid; in fact, it meets the definition of a gel, except that it is not colloidal. Under small stresses of short duration it responds both elastically and plastically, by far the greater part of the deformation being plastic. This is true even of pastes thin enough to be poured.

When the strain produced by a sufficiently large force exceeds a limit, the material fails in shear, either with or without dilation, depending on the size and concentration of the particles. Thus when a paste (or a concrete) is forced through a pipe, the deformation is laminar at first (as it is in fluid flow) until a limiting strain is reached, whereupon the material fails in shear at the pipe-wall, the flow from then on being " plug-flow." With dilute pastes, plug-flow can be converted to viscous flow by producing high rates of flow. With concentrated pastes (or concretes) continuous viscous flow cannot be produced because of dilation due to particle interference.

The fact that a normal paste meets the definition of a solid, even exhibiting some elasticity, seems at first to constitute an anomaly, for the particles are not in direct contact with each other. However, these facts, put together, only support the conclusion that interparticle attractions are effective across intervening layers of water. It seems self-evident that the cohesiveness, or stickiness, of the paste arises largely from these interparticle forces that give the paste its rigidity.

In contrast to the behaviour described, mixtures of silica in water, cement in alcohol, or any other suspension in which the particles are not at all flocculated, act like fluids ; they may be mobile, but they are not plastic, and in the absence of entrained air have only the cohesiveness of the suspending medium. Thus the question whether dispersion would be advantageous raises the question whether a fluid paste would be preferable to a plastic one. It has not been demonstrated that concrete made with a fluid paste is more workable than one made with a plastic paste. The plastic paste would seem much to be preferred. This is indicated by the undesirable results obtained when pulverised silica, in the absence of a flocculating material such as lime, is used instead of cement. It is indicated also, and very strongly, by the nature of the sediment formed from dispersed suspensions. The dispersed suspension tends to stratify, but in concrete this is probably less serious than the fact that the sediment formed is very compact and rigid, and difficult to redisperse, in contrast to a flocculated sediment which may be only a little less plastic than the original suspension. During any delay in placing, a dispersed paste would exhibit very undesirable characteristics.

Dispersing Agents.

With given materials the consistency of fresh concrete depends on (1) the quantity of paste, and (2) the consistency of the paste. Entrained air is considered to be a part of the paste. Among the materials sold as dispersing agents that have been tested, all changed both the quantity and consistency of the paste in a given mix. One material apparently softened the paste but had little effect on paste volume. Among the agents that influenced both volume and consistency of paste, all caused air entrainment and some apparently reduced interparticle attraction as did the one that had no effect on paste volume. None of these materials when used in concrete in recommended quantities produced dispersion as defined here ; that is, they all left the pastes in the flocculated state, but some of them seemed to reduce the intensity of interparticle attraction. When a paste of cement and kerosene is made, interparticle attraction is so strong that the cement particles form a relatively rigid structure capable of supporting a small weight. The addition of a very small amount of oleic acid during mixing will produce a noticeable change in appearance and a softening of the paste. This change continues as the dispersing agent is added drop by drop, with constant stirring, the paste becoming much like cement-water paste in consistency and texture. In this state it will " bleed " like cement paste and have similar plasticity. Finally, a single drop of oleic acid (in about 500 c.c. of paste) will

cancel interparticle attraction, that is, it will produce a state of dispersion. Thus varying the concentration of a dispersing agent will change the consistency, cohesiveness, and "bleeding" characteristics of a paste even though actual dispersion is not produced. When one of these agents was present, slightly less paste was required for a given slump; this is the only evidence, other than observations of the behaviour of very dilute suspensions, that interparticle attraction was reduced. It is reasoned that since the average aggregate-particle spacing was less when the agent was present, and since the slump was the same, the paste containing the agent must have been softer. This reasoning arises directly from the observation that the higher the water-cement ratio of the paste the less paste required for a given slump. It may be deduced from the tests that when using this particular agent with the materials used in the tests, the same amount of slump can be obtained with about 5 per cent. less cement than the amount required when not using the agent. From the fact that the agent reduced the water requirement for a given slump, it cannot be concluded that workability and other properties were benefited. The effect of using the agent was to replace a given paste with a smaller quantity of a softer paste. To conclude that this constitutes an improvement in workability would require also the conclusion that lean mixes are more workable than richer ones at the same slump, whereas the fact is that richer mixes are preferable under most conditions because of their greater cohesiveness, greater capacity for plastic deformation, and greater ability to keep the aggregate from settling while the fresh concrete is in transit. A softening of the paste by reducing interparticle attraction would, in concrete of a given slump, give relatively less of these desirable characteristics. Except in very rich mixes where the paste volume is higher than is necessary for satisfactory workability, the general desire seems to be to enhance these properties by stiffening the paste and increasing its volume; such is the effect of adding mineral powders or increasing the cement content. A cement of high specific surface makes a stiffer and more cohesive paste than does a coarser one at the same water-cement ratio. Yet experience shows that only in very rich mixes is it necessary to use more water (or more paste) when a cement of high specific surface is substituted for a coarser one. This indicates that in some circumstances a stiffening, rather than a softening, of the paste is advantageous. Mr. Henry L. Kennedy has reported that although no amount of water would make a sand-and-gravel mixture plastic, air entrained in the mixing water with a suitable agent made the mix appear as if it had been made with cement paste; entrained air has a stiffening effect. In general it seems that increasing the stiffness of the paste appears to be advantageous under ordinary conditions in mixes containing less than about 520 lb. of cement per cubic yard ($1\frac{1}{2}$ in. maximum size aggregate) or if the water-cement ratio exceeds about 0·5 by weight.

The lack of benefit from weakening the force of flocculation is probably due to the fact that the cement particles are normally not very strongly flocculated. It seems likely that if cement in water were flocculated as strongly as is cement in kerosene, a reduction in interparticle attraction might be beneficial in most, if not all, circumstances. But, in view of the relative weakness of the flocculating

forces in cement-water paste, the value of further reductions in interparticle attraction is debatable.

Inter-particle Attraction.

The use of some agents causes a pronounced increase in the air content of cement paste or concrete without appreciable effect on interparticle attraction. Any mechanical process that mixes a liquid with a gas tends to form a foam, although the foam may be scant and its life extremely short. If an agent is added that lowers the surface tension of the liquid a foam forms more easily and it usually lasts longer than it does without the agent, especially if the agent, by reason of its adsorption at the air-liquid interface, enables the films to withstand shocks. Many organic compounds have this effect when used with water, the soaps being perhaps the most common class. A molecule of soap is relatively large, of the long-chain variety, having a hydrophilic " head " and a hydrophobic " tail." Such molecules tend to collect at the boundary between water and air (or water and oil) and, according to theory, array themselves in such a way that the hydrophilic part remains in the water and the less wettable (hydrophobic) remains in the air. These molecules thus create a boundary film which lowers the surface tension of the water and stabilises any foam that is formed by mechanical action. When such materials are used with Portland cement paste the entrained air is probably not to be regarded as a foam, strictly speaking. But the individual bubbles scattered through the paste are no doubt stabilised by the same mechanism that stabilises the foam ; therefore, it is appropriate to speak of such materials as foam stabilisers or air-entraining agents.

In tests made with another air-entraining agent, in every case the increase in air content was accompanied by a decrease in water content directly proportional to the increase in air content. But since the decrease in water was not as great as the increase in air, the paste content also increased in direct proportion to the increase in air content. Each extra 1 per cent. of air replaced only 0·3 per cent. or less of water, and the paste content increased. Since the paste required for a given slump increases in direct proportion to the increase in air content, it must be concluded that entrained air stiffens the paste. It follows that when the water content is not reduced the increase in slump caused by entraining air in a given concrete is due to the increase in paste content and not to a softening of the paste.

Tests show, for example, that a paste for which the water-cement ratio was 0·583 and the air-cement ratio 0·12 had the same consistency as one for which the water-cement ratio was 0·447 and the air-cement ratio 0. Thus, introducing 0·12 c.c. of air per gramme of cement stiffened the paste as much as would reducing the water-cement ratio from 0·583 to 0·447, that is, reducing the water content to 0·136 c.c. per gramme of cement. It is not likely that pastes of these compositions would show exactly the same consistency if tested separately from the concrete, for the effectiveness of the air is probably influenced by the aggregate. Nevertheless, the data show conclusively that entrained air has a stiffening effect even though it is more fluid than the water it displaces. A correct explanation

of the effect would undoubtedly involve the surface tension at the numerous air-water interfaces. The tests indicate that the agent had no softening effect on the paste, that is, it did not reduce interparticle attraction. In general it appears that the lower the cement content the greater the reduction in water requirement per unit increase in air content. So far as workability and " bleeding " characteristics are concerned, the effect of entrained air may be regarded as highly beneficial. It increases cohesiveness, it aids in holding the aggregate from settling while the concrete is being transported, and the increase in paste volume increases the capacity for plastic deformation. Entrained air reduces strength, but greatly increases resistance to frost action.

Whether or not the properties of the hardened concrete are benefited equally, or at all, by agents of this type is a question that cannot be dealt with in general terms. Experience indicates that some agents have no effect on the chemical processes of hardening and therefore the effects on strength can be predicted fairly well from the effect on the voids-cement ratio. Other agents, especially those that influence interparticle attraction, are liable to retard hydration and, apparently for that reason, some are sold with an added accelerator. Agents of this type have different effects on different cements.

With respect to durability entrained air is beneficial, and some agents can be recommended where special protection against frost action is necessary. The beneficial effect of entrained air on durability is probably the result of providing room for expansion of water during the process of freezing. It is difficult to see how either dispersion, *per se*, or a weakening of the forces of flocculation in the absence of air entrainment, could have much influence on frost resistance.

The Cement Industry in Sweden.

According to the annual report of the *Skånska Cement A.B.*, a concern which controls practically all the Swedish production of Portland cement, 743,000 tons of cement were produced at the company's works during 1945. The consumption of cement was 19 per cent. higher than in 1944, and exceeded the previous record of 1939 by 7 per cent. The shortage of coal continued to hinder production. During the latter part of the year the company was allotted some American coal, and from its own mines and peat bogs in southern Sweden the company obtained 10,000 tons of inferior coal and 40,000 tons of peat. It is hoped to arrange the use of oil fuel to a considerable extent. The capacity of the company's works at Köping in central Sweden will be increased by 160,000 tons, or more than doubled, when extensions now going on are completed. The company proposes to build a new cement works south of Stockholm by the end of 1947, with a capacity of about 320,000 tons a year.